Macroinvertebrate Monitoring as an Indicator of Water Quality: Status Report for Pipestone Creek, Pipestone National Monument, 1989-2002

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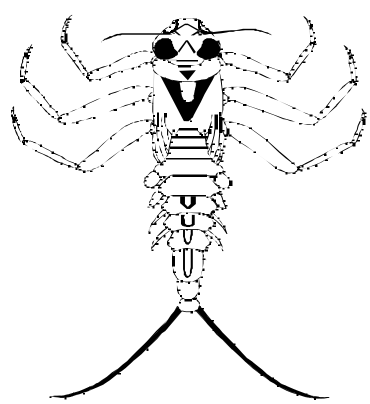

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We would like to thank all of those who have contributed to macroinvertebrate monitoring at Pipestone National Monument, Minnesota over the years. In particular, we would like to thank Kristin Legg, Natural Resource Manager and the numerous seasonal employees who assisted with macroinvertebrate sample collection. We would also like to thank personnel with the Minnesota Youth Conservation Corp who have assisted with sampling. A debt of thanks is owed Lisa Thomas and Daren Carlisle, both have assisted in numerous ways to keep this monitoring focused and the results of highest quality.

INTRODUCTION

The National Park Service (NPS) began monitoring the aquatic macroinvertebrates of Pipestone Creek in 1989, with that year's data serving as a baseline (Harris et al. 1991). Sporadic sampling continued during the period 1992-1995, with funding provided by the Midwest Regional Office of NPS. Concerted monitoring efforts began again in 1996, following creation of the Prairie Cluster Prototype Long-term Ecological Monitoring Program (Prairie Cluster LTEM) – a base-funded science program to monitor natural resources at Pipestone National Monument and five other Midwestern NPS units. The purpose of this report is to summarize macroinvertebrate monitoring data collected in 1996 through 2002 and to assess changes in community structure through time, especially since the 1989 baseline year.

Benthic macroinvertebrates are the most common group of organisms used to assess water quality (Rosenberg and Resh 1993). They are attractive as indicators because they represent a diverse group of long-lived, sedentary species that react strongly and often predictably to human influences on aquatic systems (Cairns and Pratt 1993). The objectives of this biomonitoring program are to determine the annual status of stream macroinvertebrate communities in order to assess the water quality of Pipestone Creek and to detect changes through time in macroinvertebrate communities.

BACKGROUND

Pipestone Creek, a tributary of the Big Sioux River, meanders from east to west about 100-km through southwestern Minnesota – southeastern South Dakota. The creek originates 19.3-km northeast of Pipestone National Monument as a drainage ditch near Holland, Minnesota (Harris et al. 1991). The creek merges with Split Rock Creek near Jasper, Minnesota before entering the Big Sioux River approximately 80.0-km southwest of the park near Corson, South Dakota. The city of Pipestone, Minnesota lays on the south side of the creek and borders the park on the south end. Pipestone Creek flows through the center of the park and widens twice within its boundaries to form Lake Hiawatha and an unnamed pond. A recreational lake on Pipestone Creek borders the Monument on the west side.

Natural vegetation of the area is bluestem prairie (Kuchler 1964, Stubbendieck and Willson 1986). However, agricultural row cropping is the primary land use in the watershed. The area is part of Omernick's (1987) Northern Glaciated ecoregion, with a Precambrian era bedrock of Sioux Quartzite. Pipestone, a thin layer of sedimentary rock underlying the Sioux Quartzite, has been mined heavily in the region for over 400 years. Active quarries are still found within Pipestone National Monument. A natural waterfall within the park was lowered 2.5 to 3.0 m in the early 1900's resulting in increased sedimentation of the waterway downstream (Harris et al. 1991).

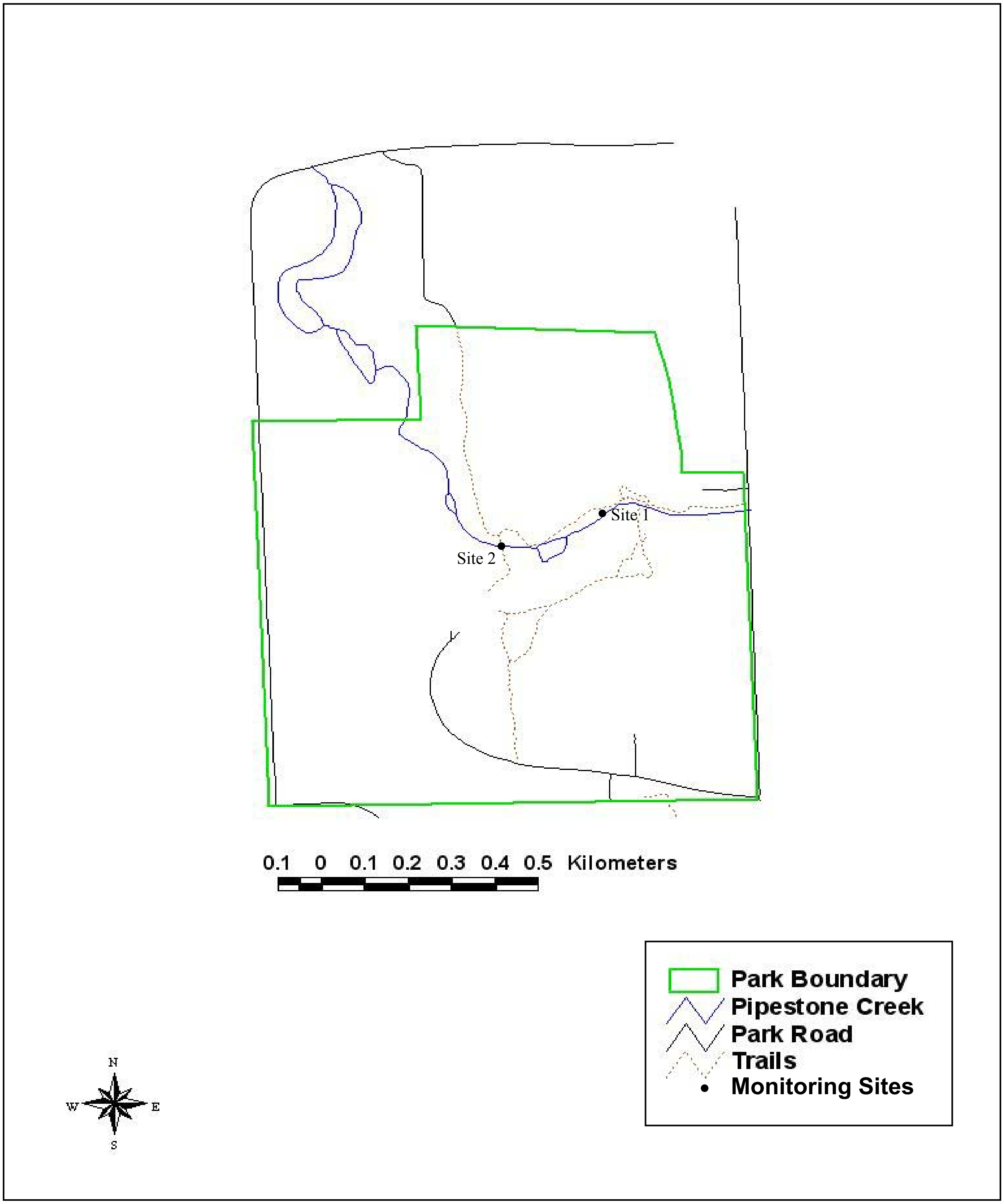
Pollution History. Water pollution within the watershed is primarily of agriculture in nature. The city of Pipestone, Minnesota releases effluent into Pipestone Creek below the park boundary. Water Resources Division, National Park Service, conducted an extensive review of historic water quality data for an area three miles upstream and one mile downstream of the park (Water Resources Division 1999). Water Resource Division identified periods since 1974 when dissolved oxygen, pH, cadmium, copper, lead, and zinc have exceeded their respective EPA criteria for the protection of freshwater aquatic life. Concentrations of nitrate, nitrite plus nitrate, chloride, cadmium, lead and methylene chloride have exceeded EPA drinking water criteria during monitoring events since 1974. Fecal-indicator bacteria concentrations and turbidity have also exceeded Water Resource Division screening limits for freshwater bathing and aquatic life, respectively. Currently, Pipestone Creek is listed by the state of Minnesota as a 303d waterway due to fecal coliform contamination. Monitoring efforts prior to 1974 were not identified in the Water Resource Division report (1999) or for this report.

METHODS

The details of field and laboratory procedures are described in Peterson et al. (1999), and summarized below.

Monitoring Sites. Harris et al. (1991) established two monitoring sites within the park, along Pipestone Creek (Figure 1). Five replicate Surber samples were collected at each site during each sampling event.

Figure 1. Macroinvertebrate monitoring sites at Pipestone National Monument, Minnesota.



Sampling Frequency And Timing. The monitoring protocol calls for the collection of five replicate samples from each of two sites at approximate monthly intervals during a summer sampling window defined by growing degree days (i.e. days with average daily temperature above 10°C). For Pipestone National Monument, normal average daily temperatures fall within this range for the period 18 June through 18 September (National Weather Service). The samples included in this report were collected between 20 June and 23 September.

Field Sampling. Benthic macroinvertebrate samples were collected from shallow riffle areas of the stream with a surber sampler following methods outlined by Peterson et al. (1999). To minimize disturbance of a site prior to sampling, samples were collected from the most downstream riffle at a site first and then progressing upstream until five samples were collected for that site. A small rake was used to dislodge organisms from the substrate inside the sampler. Cobble inside the sampler was scrubbed with a vegetable brush to dislodge additional organisms. Macroinvertebrates were carefully removed from the sampler and placed in labeled jars containing 80 % ethyl alcohol. Samples were then prepared for shipping and sent to a lab for species identification and enumeration.

Colorado State University investigators collected macroinvertebrate samples in 1989 (Harris et al. 1991). Park staff and cooperators collected macroinvertebrate samples for the period 1996-2002.

Macroinvertebrates were identified and enumerated by Dr. Boris Kondratieff's lab, Colorado State University for the period 1989 (Harris et al. 1991); and by Dr. Charles Rabeni's lab, Missouri Cooperative Fish and Wildlife Research Unit, University of Missouri-Columbia for 1996-2002. Macroinvertebrates were identified to the lowest taxonomic level possible, which was generally to genus.

To insure the consistency of data collected in the future, Dr. Charles Rabeni's lab has agreed to annually process collected macroinvertebrate samples for the next five years, with contract extensions possible thereafter. NPS personnel at Pipestone National Monument will continue to collect five replicate macroinvertebrate samples from each of two sites, three times annually. Additional physical and chemical parameters will be measured each time a macroinvertebrate sample is collected and incorporated into future water quality analysis.

Community Indices. The monitoring protocol recommended using a suite of four community indices to describe changes in community structure (Table 1; Peterson et al. 1999). Peterson (1996) identified four metrics to be the least redundant and most indicative of water quality from a list of nine metrics using Pearson correlation comparisons and a Principal Components Analysis of the correlation matrix. Additionally, we include Taxa Richness and EPT Richness in this report for the purposes of comparison with macroinvertebrate monitoring data from other sources.

Table 1. Metrics used to characterize the aquatic macroinvertebrate communities of Pipestone Creek, Pipestone National Monument, Minnesota and chosen as indicative of changing water quality through time. An asterisk indicates metrics originally selected by Peterson (1996).

Metric(Reference)	Definition	Expected Response
EPT Richness (Resh and Grodhaus 1983)	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa present per sample.	Lower richness indicates that a stream may have been subjected to one or more pollution stresses. In general, the majority of taxa in these three orders are pollution sensitive.
EPT Ratio* (Resh and Grodhaus 1983)	EPT/(EPT + Chironomidae) The number of EPT individuals in a sample divided by this sum plus the number of Chironomidae.	Lower EPT Ratio indicates that a stream may have been subjected to one or more pollution stresses. A stressed habitat reflects an imbalance between pollution-tolerant Chironomidae and pollution-sensitive EPT taxa.
Family Diversity* (Shannon-Wiener 1949)	$H' = -\Sigma(n_i / N)*\ln(n_i / N)$ N is the total number of individuals in a sample and n_i is the total number of individuals in the *i*th family.	Lower diversity indicates that a stream may have been subjected to one or more stresses.
Family Richness* (Resh and Grodhaus 1983)	Number of families present per sample.	Lower richness indicates that a stream may have been subjected to one or more stresses.
Family Biotic Index* (Hilsenhoff 1988)	$FBI = \Sigma n_i a_i / N$ N is the total number of individuals in a sample, n_i is the total number of individuals in a family, and a_I the tolerance value for the *i*th family.	Higher FBI indicates that a stream may have been subjected to one or more stresses. This index weights the relative abundance of each family by its relative pollution tolerance value to determining a community score. Therefore, pollution-tolerant species are weighted heavier than pollution-sensitive species in the index.
Taxa Richness (Resh and Grodhaus 1983)	Number of all taxa present per sample.	Lower richness indicates that a stream may have been subjected to one or more stresses.

Statistical Analysis Methods. The macroinvertebrate indices for Pipestone Creek were compared graphically using means and an estimate of variance. This analysis approach was chosen over other statistical analysis options given there was an imbalance among years in the number of samples. Specifically, in 1988 and 1996 samples were collected on only one date. During 1997–2002 samples were collected on three different dates within each year. Also, within some years June samples tended to be more variable than July, August or September samples (Appendix A). On each date, two sites were sampled with five observations (replicates) at each site. The exception being 13 July 1998 when only four replicates were collected at site one.

Annual means and standard errors were calculated from means for each sample site and date. These means and standard errors, when graphed were used to make annual water quality comparisons for Pipestone Creek within the monument. As more data is collected, annual variations in the water quality of Pipestone Creek will be investigated using more rigorous statistical methods. The U.S. Geological Survey has agreed to undertake a project to design a statistical analysis of trends in water quality of Pipestone Creek based on collected data. Both the correlation of data collected at the same site through time and the lack of independence of samples collected at a site on any given date, will be considered in this future design.

RESULTS AND DISCUSSION

The macroinvertebrate indices for Pipestone Creek across years are reported in Table 2 and Figure 2. The data are also reported by date and sampling site in Appendix A.

Table 2. Pipestone Creek, Pipestone National Monument, Minnesota macroinvertebrate indices; means and standard errors.

	Mean (SE)							
Macroinvertebrate Index	**1989 n = 2**	**1996 n = 2**	**1997 n = 6**	**1998 n = 6**	**1999 n = 6**	**2000 n = 6**	**2001 n = 6**	**2002 n = 6**
EPT Richness	3.10	3.20	2.67	1.23	6.20	4.53	4.20	5.70
	(0.1)	(0.00)	(1.23)	(0.20)	(0.38)	(0.47)	(0.21)	(0.51)
EPT Ratio	0.63	0.62	0.36	0.53	0.32	0.23	0.40	0.40
	(0.05)	(0.13)	(0.06)	(0.11)	(0.05)	(0.06)	(0.03)	(0.05)
Family Diversity	1.66	1.44	0.94	0.90	1.16	1.09	1.19	1.30
	(0.03)	(0.27)	(0.17)	(0.10)	(0.14)	(0.16)	(0.13)	(0.10)
Family Richness	8.80	6.60	5.27	3.33	9.43	9.33	6.87	8.40
	(0.00)	(2.20)	(1.57)	(0.27)	(0.96)	(1.02)	(0.74)	(0.88)
Family Biotic Index	5.32	4.85	5.12	4.67	5.34	5.59	5.38	5.17
	(0.14)	(0.14)	(0.21)	(0.33)	(0.12)	(0.11)	(0.10)	(0.07)
Taxa Richness	12.5	9.20	8.33	4.22	15.03	14.00	10.73	13.87
	(0.30)	(3.00)	(2.45)	(0.53)	(1.00)	(1.49)	(1.09)	(0.94)

Richness, the number of taxa at a given taxonomic level, indicates that water quality is improving slightly in Pipestone Creek since 1998 (Table 2 and Fig. 2). EPT taxa richness (Fig. 2a), family level richness (Fig. 2d) and the richness of all taxa observed (Fig. 2f) have all increased significantly with time based on comparisons of means and standard errors. All three levels of richness have equaled or exceeded the baseline levels of 1989. Based on means and standard errors, EPT richness (the richness of pollution intolerant Ephemeroptera, Plecoptera and Trichoptera taxa) has improved the most with time.

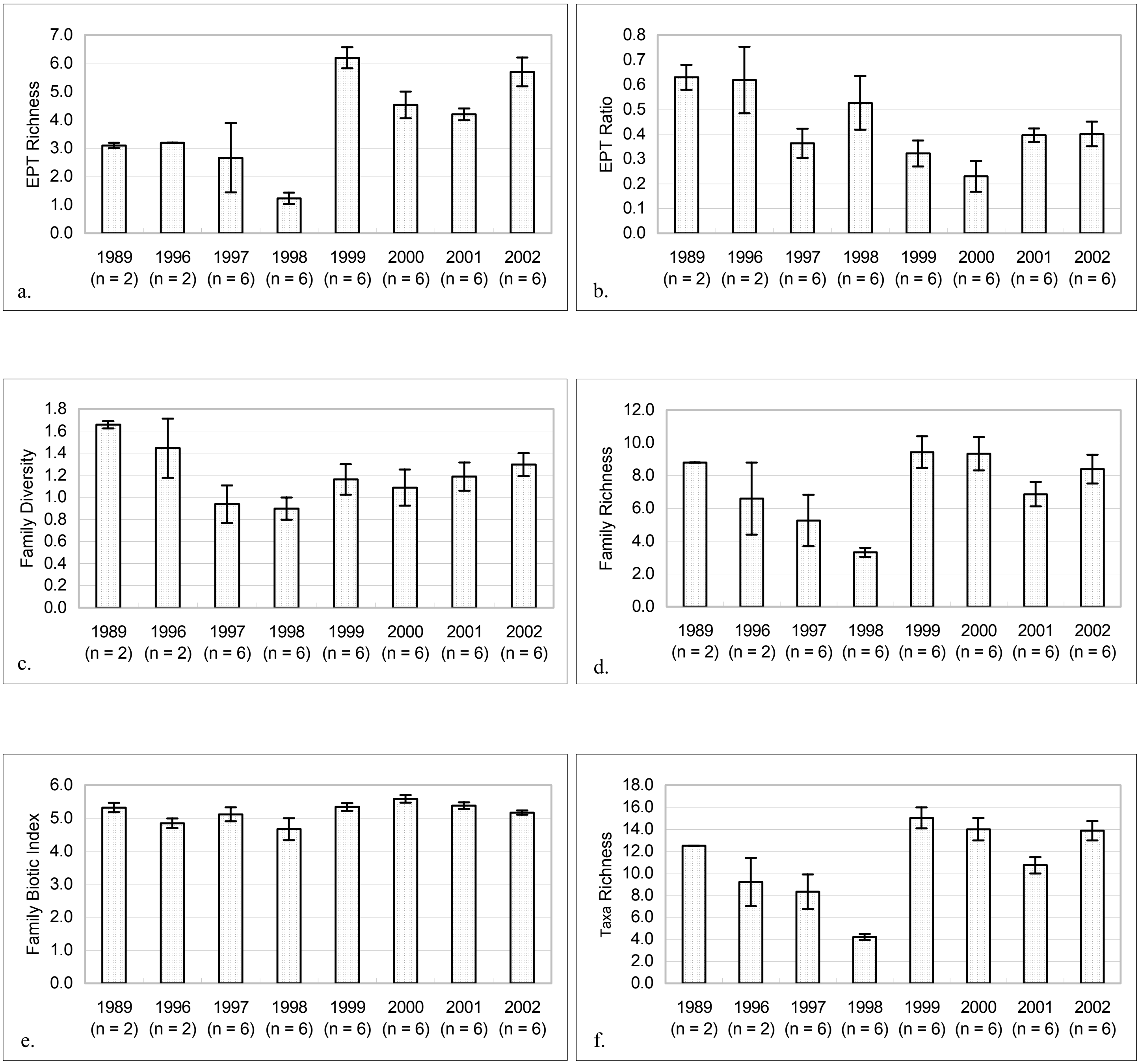
Although species richness indicates improving water quality, three metrics based on numbers of individuals: EPT ratio (Fig. 2b); Family Diversity (Fig. 2c); and Family Biotic Index (Fig. 2e) indicate the opposite. The EPT ratio, a measure of the number of individuals in the EPT taxa to the number of pollution tolerant Chironomids, has declined significantly. Comparing the EPT richness to EPT ratio suggest that while the number of EPT taxa have increased the percentage of the population made up of individual Chironomidae has also increased. Our data does in fact show that Chironomidae have increased 306%, 537%, 149% and 319% over our baseline average of 376 individuals per site per sample date for years 1999-2002. The numbers of

Chironomidae in 1996 – 1998 were below the baseline year by 93%, 50% and 95%, respectively. Family diversity may also reflect this same change in community composition, as it has declined significantly between 1989 and 2000, with only a slight improvement observed since 2000. Increasing Chironomidae numbers has skewed the distribution of individuals to this family, thus lowering community diversity and out-gaining any positive effects of increased EPT richness on diversity.

The Family Biotic Index, a weighted measure of individuals in a population, has also increased significantly since 1998 and was higher in 2000-2001than the baseline year, 1989. Weighting is based on the pollution tolerance of each family, with more tolerant families having a higher weighting factor thus contributing more to the index (Table 1). Less tolerant families, or those with few individuals, contribute less to the index. Increasing Family Biotic Index values is the result of increasing pollution tolerant Chironomids and their higher tolerance values.

In summary, the macroinvertebrate data has provided us with a complex and conflicting picture of the water quality of Pipestone Creek within Pipestone National Monument. It appears that there has been an increase in pollution intolerant species (EPT richness) suggesting water quality is improving. This finding is supported by increases to Family and all Taxa Richness. However, the substantial increase in Chironomids and the associated declines in EPT Ratios and Family Diversity suggest the opposite. The increase in the number of Chironomidae has produced an unequal or skewed distribution of individuals among families resulting in lower diversity values. The influence of increasing Chironomidae has offset the positive effects of increased EPT richness on diversity. Our Family Biotic Index values also suggest declining water quality. Without a clear process for determining which metric carries more weight in determining water quality, it is prudent to take a conservative approach and say that water quality of Pipestone Creek has remained relatively stable between 1989 and 2002. However, increasing numbers of Chironomidae suggest that there is an increasing source of stress on water quality in Pipestone Creek either within or above the Monument. An expansion of the water quality monitoring within the Monument to include chemical and physical measures, as well as the biotic measure, seems warranted at this time based on the conflicted results reported. Both chemical and physical measures will help identify potential cause for changes in the biotic community as well as serve as indicator of changing water conditions themselves.

Figure 2. Pipestone Creek, Pipestone National Monument, Minnesota macroinvertebrate index means (standard error) by sample years.



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Appendix A. Pipestone Creek, Pipestone National Monument, Minnesota macroinvertebrate index means (standard error) by sample date and sample site.

Date	n	Taxa Richness	Family Richness	Family Diversity	EPT Richness	EPT Ratio	FBI
			Pipestone Creek Site 1				
06/22/89	5	12.80 (0.66)	8.80 (0.86)	1.69 (0.11)	3.20 (0.20)	0.68 (0.04)	5.46 (0.07)
08/07/96	5	6.20 (0.80)	4.40 (0.75)	1.18 (0.19)	3.20 (0.73)	0.75 (0.08)	4.99 (0.41)
06/26/97	5	19.60 (2.82)	12.20 (1.71)	1.23 (0.21)	8.40 (0.87)	0.25 (0.08)	5.69 (0.19)
08/13/97	5	3.40 (1.36)	2.40 (0.93)	0.54 (0.29)	1.40 (0.68)	0.60 (0.19)	5.18 (0.55)
09/23/97	5	3.80 (0.8)	2.00 (0.45)	0.47 (0.20)	0.80 (0.37)	0.24 (0.13)	5.62 (0.23)
07/13/98	4	5.50 (0.96)	3.75 (1.03)	1.12 (0.38)	1.00 (0.58)	0.29 (0.17)	6.20 (0.51)
08/19/98	5	2.20 (0.97)	2.20 (0.97)	0.47 (0.32)	0.80 (0.58)	0.28 (0.18)	4.68 (1.38)
09/13/98	5	4.40 (1.03)	3.20 (0.49)	1.02 (0.18)	2.00 (0.32)	0.88 (0.08)	4.22 (0.26)
07/13/99	5	16.20 (1.88)	9.20 (0.86)	1.11 (0.13)	7.00 (0.45)	0.29 (0.07)	5.42 (0.12)
08/16/99	5	12.80 (1.28)	7.80 (1.02)	1.07 (0.10)	5.80 (0.49)	0.39 (0.07)	5.18 (0.16)
09/15/99	5	12.00 (0.95)	7.40 (0.81)	1.04 (0.11)	5.40 (0.68)	0.44 (0.13)	5.11 (0.25)
06/20/00	5	16.00 (1.79)	7.60 (1.03)	0.70 (0.12)	5.00 (0.71)	0.12 (0.04)	5.84 (0.09)
07/21/00	5	11.60 (2.79)	8.00 (1.64)	1.01 (0.34)	4.00 (1.45)	0.24 (0.10)	5.59 (0.15)
08/22/00	5	7.80 (0.20)	6.00 (0.32)	0.78 (0.11)	2.60 (0.24)	0.18 (0.05)	5.59 (0.12)
07/18/01	5	9.00 (2.07)	5.60 (0.75)	0.97 (0.16)	3.80 (0.86)	0.37 (0.11)	5.34 (0.19)
08/23/01	5	10.60 (1.29)	5.80 (0.73)	1.08 (0.06)	4.20 (0.73)	0.42 (0.04)	5.49 (0.22)
09/12/01	5	6.60 (1.66)	4.40 (1.03)	0.82 (0.22)	4.00 (0.84)	0.50 (0.18)	5.06 (0.36)
7/10/02	5	15.60 (3.91)	8.60 (2.07)	1.14 (0.36)	6.60 (1.52)	0.31 (0.20)	5.47 (0.42)
8/13/02	5	13.2 (1.10)	6.60 (0.89)	1.14 (0.20)	7.20 (0.45)	0.50 (0.16)	5.16 (0.29)
9/18/02	5	9.80 (3.11)	5.00 (1.73)	0.97 (0.19)	5.00 (1.58)	0.55 (0.28)	5.00 (0.62)
			Pipestone Creek Site 2				
06/22/89	5	12.20 (0.37)	8.80 (0.58)	1.62 (0.07)	3.00 (0.00)	0.58 (0.04)	5.18 (0.24)
08/07/96	5	12.20 (2.42)	8.80 (1.02)	1.71 (0.14)	3.20 (1.24)	0.48 (0.17)	4.71 (0.14)
06/26/97	5	9.80 (1.77)	7.00 (1.45)	1.56 (0.30)	3.60 (1.12)	0.45 (0.11)	4.91 (0.29)
08/13/97	5	7.40 (1.78)	4.60 (1.08)	1.03 (0.14)	1.20 (0.58)	0.38 (0.19)	4.99 (0.23)
09/17/97	5	6.00 (1.22)	3.40 (0.51)	0.80 (0.16)	0.60 (0.24)	0.26 (0.19)	4.31 (0.67)
07/13/98	5	3.20 (0.97)	3.20 (0.97)	0.78 (0.28)	1.20 (0.37)	0.80 (0.20)	4.71 (0.84)
08/19/98	5	4.60 (1.12)	3.40 (0.51)	0.92 (0.11)	0.80 (0.37)	0.34 (0.20)	4.33 (0.47)
09/13/98	5	5.40 (1.54)	4.20 (1.02)	1.09 (0.17)	1.60 (0.51)	0.57 (0.19)	3.86 (0.43)
07/13/99	5	14.00 (1.52)	7.60 (0.51)	0.75 (0.10)	5.00 (0.89)	0.14 (0.02)	5.79 (0.07)
08/16/99	5	17.80 (0.92)	11.60 (1.03)	1.23 (0.20)	7.20 (0.49)	0.22 (0.05)	5.53 (0.08)
09/15/99	5	17.40 (0.93)	13.00 (1.00)	1.77 (0.09)	6.80 (0.58)	0.46 (0.11)	5.03 (0.20)
06/21/00	5	17.40 (1.57)	11.20 (0.73)	0.87 (0.10)	5.80 (1.02)	0.13 (0.02)	5.78 (0.04)
07/21/00	5	16.60 (2.38)	12.40 (1.44)	1.62 (0.07)	5.40 (1.17)	0.53 (0.14)	5.06 (0.30)
08/22/00	5	14.60 (1.50)	10.80 (0.73)	1.55 (0.12)	4.40 (1.17)	0.18 (0.05)	5.66 (0.28)
07/19/01	5	14.00 (2.65)	8.40 (1.72)	1.15 (0.12)	4.00 (0.71)	0.41 (0.07)	5.20 (0.18)
08/23/01	5	12.80 (1.20)	8.60 (0.68)	1.43 (0.08)	5.20 (0.86)	0.31 (0.03)	5.76 (0.12)
09/12/01	5	11.40 (0.93)	8.40 (0.40)	1.67 (0.06)	4.00 (0.55)	0.36 (0.07)	5.44 (0.12)
7/10/02	5	15.80 (1.92)	10.20 (0.45)	1.36 (0.23)	6.60 (1.52)	0.33 (0.30)	5.20 (0.65)
8/13/02	5	13.4 (3.58)	9.80 (1.92)	1.53 (0.34)	4.40 (1.14)	0.25 (0.20)	5.10 (0.53)
9/18/02	5	15.4 (1.82)	10.20 (0.84)	1.64 (0.22)	4.40 (1.67)	0.48 (0.28)	5.09 (0.53)